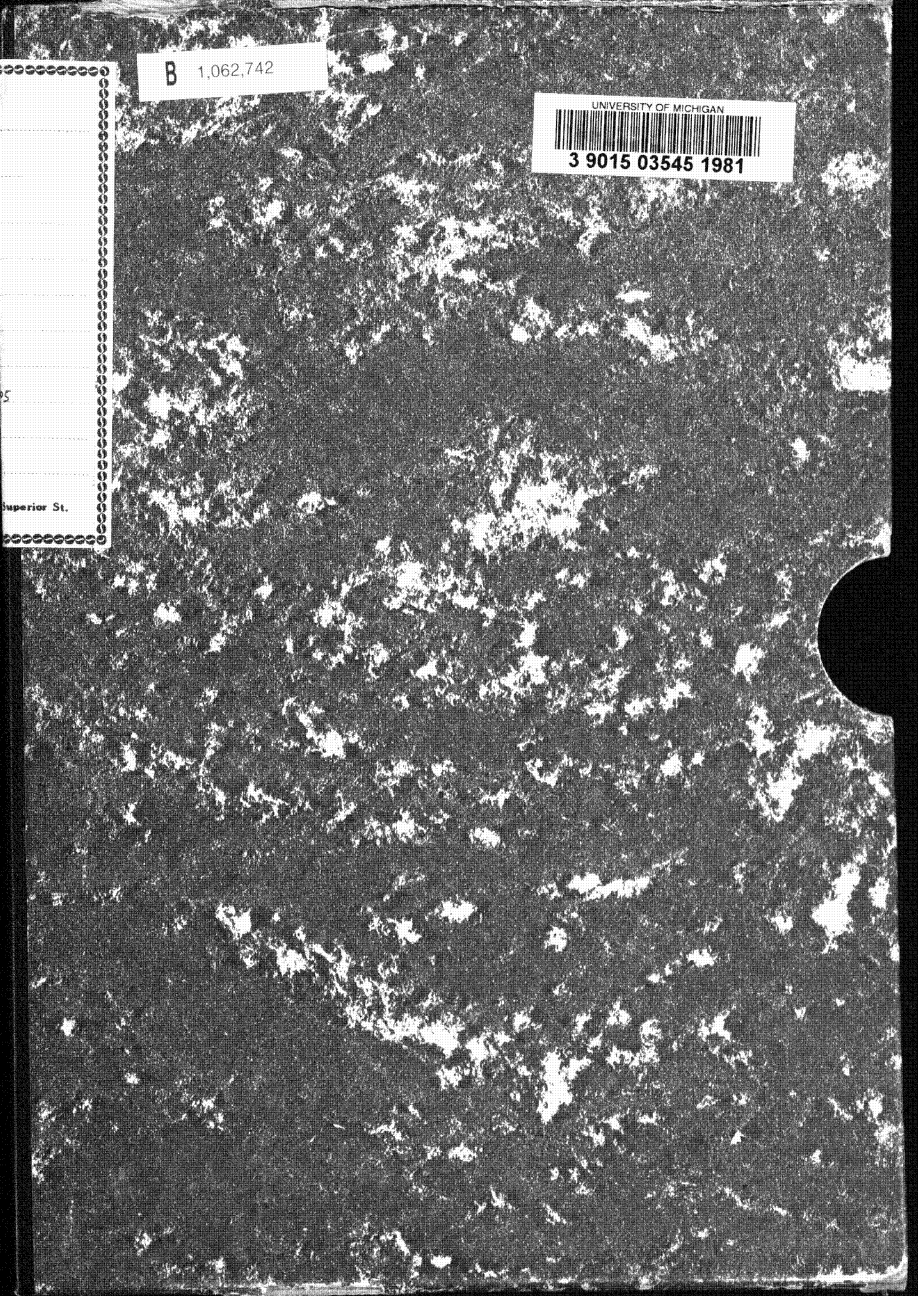

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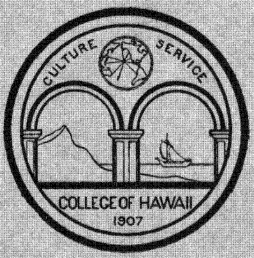
Bulletin No. 3.

A Study of the Food Habits of the Hawaiian Dragonflies or Pinau

with Reference to their Economic Relation to other Insects

Thesis presented for the degree of Master of Science, June, 1914

By ALFRED WARREN, M. S.
Under the Direction of
JAMES F. ILLINGWORTH, Ph. D.



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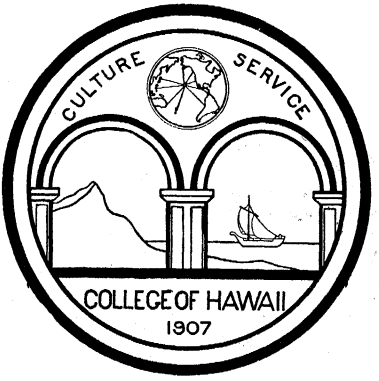

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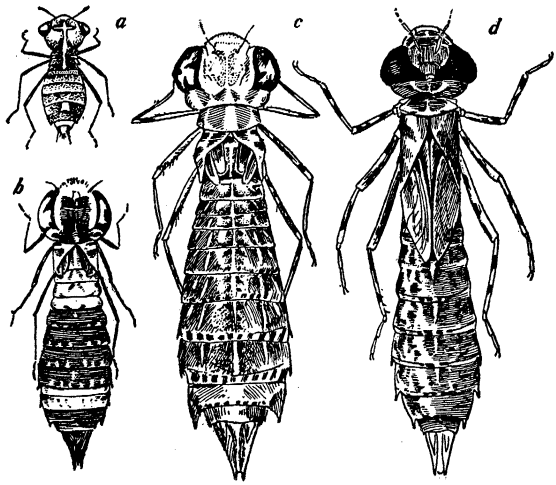

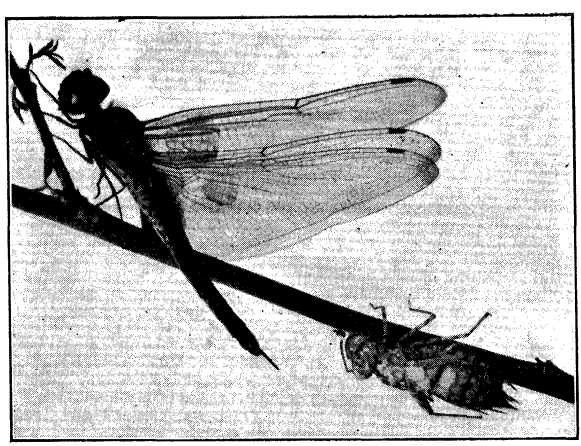

ABOVE: Stages in the development of nymph of the giant dragonfly, **Anax junius.** (a) Youngest stage; (b), (c) and (d) older stages, showing gradual development of the wings. (Slightly enlarged after Needham.)

BELOW: Original photograph showing adult dragonfly which has just emerged from nymph case; natural size.

FOOD HABITS OF HAWAIIAN DRAGON-FLIES

BY

ALFRED WARREN

From time immemorial the dragonfly has been an object both of fear and wonder. It was feared by the masses, who believed it to inflict severe pain upon both man and beast. It was admired by the student of nature for its grace and beauty and for its perfect adaptation to its mode of life, in both the nymphal and adult stages. That this creature of the air, harmless to all larger beings, but certainly fatal to most winged insects, was popularly and universally feared and that its habits were not generally well known, which is true in some localities even at the present day, can be gathered from the list of terrible names that each nation possessed and still applies to it. In our own tongue we find such names as Darning-needles, Bad-man's-needle, Devil's Darning-needle, Snake-doctor and Horse-stinger. But when it is borne in mind that these insects are all, as far as is known, predaceous throughout the nymphal and adult stages, that in the younger stages they feed on aquatic creatures, and that the adults devour any creature on wings that they are capable of mastering, the name dragon-fly seems, perhaps, the most appropriate.

General Distribution.

The order Odonata, to which the dragonfly belongs, is widely distributed and includes many species. The greater number of species are found in tropical and sub-tropical regions, yet great numbers may be found in suitable localities in the temperate zone. Already some two thousand species have been described in different parts of the world and as new species are constantly being added to the list it may be safe to say that from five thousand to ten thousand species are in existence. The most widely distributed of these species is the yellow dragonfly, **Pantala flavescens** Fabr., which is the species most common in Hawaii. Specimens of this species have been taken in almost every part of the world.

Since the dragonflies are so abundant and so widely distributed it follows that their feeding habits are likely to be of economic importance everywhere that they occur. Insect predators which are so common must devour great numbers of other insects. Are the insects thus consumed the enemies or the friends of man?

Although a great deal has been written about the dragonflies, yet practically all of this literature bears on systematic, anatomical and biological studies. Dr. Ris* makes the following remark concerning the literature on dragonflies: "The knowledge of anatomy and biology of the **Odonata** as well as the systematic works on this group of insects as a whole, can be considered as being very far advanced." In spite of this great literature on the dragonfly, we find that no extensive investigations have been carried on for the purpose of ascertaining what really constitutes the food of these predaceous insects and what economic relation they hold to the other insects. In the available literature, there could be found only two articles referring to the food of the dragonfly, and these references are limited to a few paragraphs. In one article Poulton** lists sixteen specimens of dragonfly which were caught in the act of seizing their prey, the species of the victim being identified in nearly all cases. The same author also records§ finding certain insect groups represented in the stomach contents and excreta of the dragonfly. Since so little has been published on this subject, any additional data on the food habits of the dragonfly obtained through observation or dissection of the alimentary canal, should be of interest.

Object of Study.

The object of taking up the study of the food habits of the dragonflies of these islands was to obtain some definite data as to what constitutes the food of this important group of insects and at the same time to gain some idea as to the economic relation it holds to the local insect fauna, which is so markedly different from that of any other country. Taking into consideration the small number of species of a great many families or even larger groups of insects, and the total absence of entire orders, whose members, in other countries, furnish, it is be-

* "Zoologische Jahrbuecher, Systematik" **9**, 596.
** "Trans., Ent. Soc. London," 1906, 399 et seq.
§ "Journal, Bombay Natural History Society," **20**; 1910, 236-238.

lieved, the bulk of the food of the younger stages of the dragonfly, the study of the food of this group of insects under Hawaiian conditions becomes an extremely interesting one.

Life History of Pantala Flavescens.

In order to understand the food habits of the dragonfly one must first be acquainted with the insect's life history, for its food habits differ in the different stages of its development. The life of the dragonflies may be divided into three periods: The egg, the nymph or growing stage, and the adult or mature stage. As far as can be ascertained the life history of the Hawaiian dragonflies has not been worked out in detail. It may therefore be of interest to give here the results of some breeding experiments with the **Pantala** from egg to adult.

Egg Stage.—The eggs are whitish, later becoming yellow, subspherical bodies, about 1/5 mm. by 1/3 mm. in size. They are laid singly, or a few at a time, by the female as, flying close over a body of water, she strikes the tip of her abdomen on the surface. The eggs are laid wherever there is water in the open, from a small mud-puddle in the street to a large stream or pond.

The eggs for carrying out the breeding experiments were secured by catching female dragonflies in the act of ovipositing, and collecting in a glass those eggs which were laid in large masses. The number of eggs thus obtained varied from fifty to several hundred. In one case 816 were collected in this way from a single female. Each batch was placed separately in a small Petri dish filled with water. They hatched in from five to seven days.

Nymph Stage.—The newly hatched nymph is about 2/3 mm. long. Its first activity is to moult almost immediately after hatching, increasing its length by a fraction of a millimeter. It is then ready to start out on its life-long hunt for food, which is in all cases animal life.

The following method was used in rearing the nymphs: After hatching, individual nymphs were placed in a separate Petri dish. The precaution of separating the nymphs had to be taken on account of their cannibalistic proclivities. They were fed on newly hatched mosquito larvae until about the third or fourth moult, when they were transferred to larger Petri dishes. In these dishes they were fed on larger mosquito larvae, and allowed to stay till about the sixth moult; they

were then placed in jelly glasses, kept there usually until the ninth moult, and finally transferred either to a larger glass jar or a small tank. The nymphs not segregated were left in the original Petri dishes as a reserve supply to replace any of the individuals selected for rearing, in case these should die, as it was found that the nymphs are very delicate in their younger stages.

The nymphs constituting the reserve supply were given no outside food, but were allowed to feed on their fellows; this procedure was followed principally to find out how far their cannibalistic tendency, if given a chance, would be manifest in the early stages. Often out of a lot of from 200 to 400 eggs, most of which hatched, there would be left at the end of two weeks but five or six nymphs to tell the woeful tale of cannibalism. These survivors were used in the feeding experiments as detailed elsewhere.

Table I gives an account of four nymphs that were successfully carried through from egg to adult.

TABLE I. SHOWING THE LIFE HISTORY OF FOUR SPECIMENS PANTALA FLAVESCENS FABR.

Stages of Development	Duration of the various stages of each of the 4 individuals observed				Average Time	Average Length
	No. 1 (Fem.)	No. 2 (Fem.)	No. 3 (Male)	No. 4 (Male)		
	Days	Days	Days	Days	Days	mm.
Egg Incubation Period	5	5	5	7	5½	1/3
Instars of nymphs** First	*	*	*	*	*	2/3
Second	4	5	4	3	4	1
Third	3	5	7	3	4½	1½
Fourth	2	8	6	2	4½	2 1/3
Fifth	3	8	6	3	5	4
Sixth	2	5	5	4	4	5
Seventh	3	6	5	5	4¾	6
Eighth	2	5	6	6	4¾	8
Ninth	5	4	9	5	5¾	10
Tenth	4	9	9	8	5½	13
Eleventh	8	13	14	27	11 2/3	18
Twelfth	19	30	30		26 1/3	24
Complete nymphal period	55	98	101	66	80	

* Less than ½ hour.

** Instars are the periods between moults; e. g., the first instar is the stage between the egg and first molt.

From the foregoing table it will be seen that the nymphs moult ten or eleven times; and that the time of incubation and especially the total nymphal period vary considerably with the individual. It will also be noted that the time of the last two or three instars gradually lengthens, the last, of course, being the longest, averaging, for the four, more than one-third of the life of the nymph. This long period is due to the great change that takes place during the last instar, a change from the nymphal, water-inhabiting form, breathing chiefly by means of tracheal gills, to the adult form, breathing altogether by means of tracheae. This period corresponds to the pupal stage of those insects possessing a complete metamorphosis. During this time many of the organs are greatly changed. Some are even completely reconstructed, such as the respiratory organs, labrum, wings, compound eyes and gizzard.

In these experiments the nymphal period varied from 55 to 101 days. It is doubtful if the nymphs complete their growth in nature in so short a time as did No. 1, except in very rare cases, as their food supply is not always close at hand. The amount of food, modified doubtless by climatic conditions, largely determines the rate of growth of the nymphs.

Nymphs Nos. 1 and 4 were fed daily with large amounts of food; while Nos. 2 and 3 were fed less often and in smaller quantities. The difference is brought out in that Nos. 1 and 4 completed their growth in about two months, while Nos. 2 and 3 required over three months for their development.

Food Supply Important.

Other experiments conducted along this line proved still more strikingly the relation of food to growth. Two nymphs, hatching on the same day, were placed in separate vessels. One was fed liberally with mosquito larvae, and the other was given five or six mosquito larvae every four or five days.

In nineteen days the former moulted seven times, and was well along the eight instar, whereas the latter had cast only its third moult, and at this stage was no larger than the other at its fourth instar.

The ability to fast for long periods also plays a great part in the length of nymphal life. Some experiments were carried on to see how long nymphs could go without food. The longest fasting periods, obtained in these experiments, were from

fourteen to sixteen days. Under natural conditions, however, no doubt they can keep alive without food for much longer periods. Some species of dragonfly nymphs have been kept without food in confinement for a month and more. Specimens of **Aeschna cyanea** and **Agrion puella** fasted for thirty and thirty-three days respectively* and at the end of that time were still active and apparently not at all affected by the long fast.

From the experiments detailed above it may be safely concluded that the nymphal period varies from two to six or more months.

Adult Stage.—No attempt was made to see how long the imago or adult lives, as the very active nature of the dragonfly and the manner in which it procures its food would not permit of any successful feeding in confinement. It is reasonable to suppose, however, that its life does not extend over a great many weeks, if we can draw any inference from the very advanced stage of development of the ovaries in the later stages of the female nymphs. This, however, is no definite proof, and experiments on the life of the adult dragonfly would be of very great interest. In dissecting nearly full-grown female nymphs, it was found that the ovaries were full size, and the ovarian tubes practically as long and plump as those of the adult, but no signs of any egg constrictions could be detected.

Local Distribution.

Hawaiian conditions seem to offer innumerable and in some cases extensive regions admirably suited to the dragonfly in its younger, or nymphal, stages. As all the species in their younger stages live either in water or in moist places, their preponderance depends largely upon bodies of water, or dense and more or less continuously moist forests, suited to these early stages.

The conditions requisite for the life of the nymphs vary a great deal according to the adaptation of the different species. Some require quiet, shallow water with boggy or muddy bottoms in which to burrow; some thrive best in clean sandy beds of running streams; some have their habitat in rapids where they cling to rocks and plants; still others live in deep ponds

* "Entomologist," 33; 211.

or lakes, clinging to the submerged debris and vegetation. In Hawaii, land forms or even arboreal forms are found.

Though conditions in the Islands are on the whole favorable to the development of the dragonfly in its nymphal stages, these conditions, nevertheless, vary so widely in different localities that two well marked zones may be recognized. The first comprises the lower plains of more or less open country, with their natural streams and artificial irrigation ditches leading to taro and rice fields and to other cultivated crops artificially irrigated. This region for the purposes of this study will be called the **Lower Zone.** It extends from sea level to an elevation of from 1000 to 2000 feet. The second, including the dense and more or less continually moist upland forests with their numerous mountain streams and their peculiar tropical vegetation, will be designated the **Forest Zone.**

In these two zones the nymphs have adapted themselves to entirely different modes of life. In the former they are purely aquatic. Those in the Forest Zone develop not only in the moist places underneath overhanging, dripping rocks, but also in the moisture and debris-retaining leaf-sheaths of the climbing Ieie vine, where many species of the Agrionids or damsel-flies live.

In both these zones the area suitable for the breeding of the nymphs is very extensive. On the lowlands and in the valleys in many sections of each island, there is an intricate network of irrigation ditches leading to extensive rice and taro fields. The rice crop is submerged in water for the greater part of its growing season of five months, and usually two crops are taken off in a year. The taro fields remain under water often for as long as twelve months. The area under rice cultivation on the Island of Oahu alone is about 9,000 acres.

The dragonflies of the Forest Zone are also provided with large areas, as many of the mountain slopes are well wooded. Moreover, as this is a tropical country, the breeding season goes on without interruption.

Notwithstanding all these favorable conditions extending over such large areas, there are in these islands only five species of dragonflies, or **Anisoptera,** and twenty-six species of damselflies, or **Zygoptera.** The details of these species will be taken up under another section. Though the number of species is small, the number of individuals is large, more espe cially the common yellow species, **Pantala flavescens.**

Species of Odonata in the Hawaiian Islands.

The following is a brief summary of our local dragonflies. The **Anisoptera,** or dragonflies, in the Hawaiian Islands are represented by five species, enumerated under their respective families, as follows:

LIBELLULIDAE.

Pantala flavescens Fabr.—This is the cosmopolitan, medium large, yellow species that is so common in the streets and gardens of Honolulu; in fact, it is found on all the islands, on the lower open lands. The **Pantala** is an introduced species.

Tremea lacerata Hagen.—This species is somewhat larger and darker than the foregoing. It can be recognized by the large, irregular, dark-brown patch on the base of each of the hind wings. Although the members of this species may also be found in the open country on the lowlands of all the islands, it is rather scarce. This is also an introduced species.

Nesogonia blackburni McLach.—This is much smaller than our yellow species, being the smallest of our dragonflies. The general ground color is dark. On the abdomen are a number of large blotches of red at the base, and some smaller ones near the tip, and between these there is a sprinkling of red dots along the dorsal side. On the thorax are a number of conspicuous yellow spots and stripes. These characteristics readily distinguish this species from the other four dragonflies. This one is likewise distributed over all the islands, but, as it is an endemic species, its habitat is restricted to the deep valleys and mountain forests, and is rarely met with.

AESCHNIDAE.

Anax junius Drury.—This is the large handsome blue species quite common on all the islands. In abundance it comes next to the yellow species. This is also an immigrant.

Anax strenuus Hagen.—So far this species has been found in the mountains of Kauai, Maui and Hawaii, and is endemic. It is by far the largest of our dragonflies. Superficially it is similar to **A. junius,** but is dark in color. Its wing expanse is 5 inches, against 3½ inches in our common yellow species.

The **Zygoptera,** or damselflies, found here belong to the genus **Agrion** of the family **Agrionidae,** and form a unique and interesting group. Twenty-six species have been recorded, all of which are native to the islands.

The nymphs of many of these damselflies have changed from their aquatic habit and have adapted themselves to live on land, and some have even become arboreal, living in the leaf bases of the climbing Ieie vine (**Freycinetia**) and the liliaceous **Astelia.** Dr. R. L. C. Perkins* describes their acquired land habit as follows: "These have given up their aquatic life and live hidden at the bases of the leaves of a liliaceous plant, **Astelia veratroides.** Sometimes a little water is held by the plant around the stem. but more often there is merely a collection of damp earth and dead leaves. These nymphs would even appear to dislike the collections of water, for in wet weather they

* "Fauna Hawaiiensis," 2; 63.

often crawl half-way up the leaves instead of remaining at the base, where the water accumulates."

The members of this genus are found chiefly in the mountain forests and wooded valleys, but they may be met with anywhere except in the dry regions of the coast and on the higher mountains above the forest line.

Insect Fauna of Hawaii.

Before drawing any definite conclusions as to the economic relation of the dragonflies to the rest of the insect world, it would be well to get some idea of the Hawaiian insect fauna as a whole. Therefore a brief survey of the Island fauna will be given.

As the Hawaiian Islands lie well within the tropics, in the middle of the Pacific Ocean, separated from the North American continent by 2100 miles, and from the Asiatic shores nearly 5000 miles, it is to be expected that the Hawaiian fauna and flora differ markedly from those of the continents to the east and west. Furthermore, as the fauna, especially the insect division, of any country depends directly or indirectly upon the flora, and since the Hawaiian vegetation, excluding the plants introduced since the advent of the white man, is largely endemic, and therefore peculiar to these Islands, one may expect to find a great number of native insects. Dr. Perkins,* who for years has collected not only insects but other forms of animal life in the Hawaiian Islands, and who is preeminently an authority on this subject, places the total number of species of native insects known by him, January, 1913, at 2740.** He asserts that only about half of the native species have been collected, and that a fairer estimate of the native forms would be 5780.

Since the establishment of closer commercial relations between these islands and other countries by means of freight and passenger vessels, a number of species have been brought in accidentally, and still others have been introduced purposely for economic reasons, so that this foreign group of insects has reached the number of at least 585 species. These Islands,

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* "Fauna Hawaiiensis," Introduction, p. XLI.

** The extensive faunal collections made by Dr. Perkins in the Hawaiian Islands gave rise to the comprehensive work, the "Fauna Hawaiiensis." In the review of the insects that follows the numbers of species, genera, and families mentioned are taken mainly from this work, supplemented in a few cases by the writer's own observations.

though often spoke of as possessing but a meager collection of insects, are indeed quite rich in the number of species of certain orders.

The wide range of insects existing in Hawaii may be better understood remembering the great variability in the physical conditions of the Islands. The varying topography; the great variation in rainfall in different parts of the same island; the amount of exposure to or protection from the trade winds; the great difference in temperature of the lowlands near sea level and the higher altitudes; and the luxuriant growth of vegetation in some sections and the scanty growth in others, are conditions tending enormously toward the adaptation and support of a wide range of insect forms.

There are four points that come out strikingly as one studies the local insect fauna as a whole. These are, the minuteness and obscurity of the insects inhabiting dense forests and deep gulches; the paucity in, or entire absence of large groups; the richness in number of species in certain genera, or the large number of closely allied genera in certain families; and the large number of flightless forms, especially among the beetles, **Coleoptera**, and true bugs, **Heteroptera.**

During the last fifty years great changes have taken place in the number and distribution of the insects of Hawaii, especially with regard to those in the Lower Zone. In the Forest Zone the changes are not so marked. The disturbing factors have been chiefly:

Introduction of foreign plants, and the placing under cultivation of large areas of land.

Destruction of forests for lumber.

Pasturing the foothills, plains, and valleys with sheep, cattle, and horses, thus gradually killing off the native trees and plants.

Introduction, accidentally and designedly, of foreign insects which either prey on, or crowd out, the native insects.

One insect which is responsible, more than any other of the foreign species, for the reduction of the native insects in the Lower Zone, is the predaceous ant, **Pheidole megacephala** Fabr. To quote Dr. Perkins* on the destructiveness of this ant: "It may be said that no native Coleopterous insect can resist this predator, and it is practically useless to attempt to collect

* "Fauna Hawaiiensis," Introduction, XLI.

where it is well established. Just on the limits of its range one may occasionally meet with a few active beetles, e. g., species of **Plagithmysus,** often with these ants attached to their legs or bodies, but sooner or later they are quite exterminated from such localities. It is quite certain that native beetles and many other insects are absent from the localities occupied by **Pheidole,** solely on account of its presence."

This ant is found as high as 4000 feet elevation. Broadly speaking then, in the Lower Zone the number of native species of insects has been greatly reduced, and in that region most of the introduced species are now found. The Forest Zone still contains most of the native insects and only a few of the foreign ones. In the following brief review of the local insects only the more important groups will be considered as they exist in the two zones.

As both the nymphal and adult forms of the **Odonata** are predaceous throughout their life, this review of the Hawaiian insects will be taken up mainly in their relation to the food supply of the dragonflies. For this purpose the insects will be divided into two groups, aquatic and aerial insects. The aquatic insects will include all those habitually frequenting the water, or living in that medium all their lives, or at some stage during their life history; that is, insects which furnish food for the nymphs. The aerial insects will embrace all those possessing functional wings; that is, insects that may form possible food for the adult dragonflies.

AQUATIC INSECTS.

The streams and other bodies of water in Hawaii are remarkably lacking in aquatic insects. As mentioned, entire orders, common in the streams and ponds of other countries, are unrepresented, e. g., **Ephemerida** or May-flies; **Mecoptera** or Scorpion-flies; **Plecoptera** or Stone-flies; and **Trichoptera** or Caddice-flies. Most of the families of the water bugs have no representatives here. Out of the eleven families* whose members live in the water, only four, **Corisidae, Naeogeidae, Notonnectidae,** and **Veliidae,** are found locally, and each of these is represented by only one species. Besides these four a few species of **Acanthiidae** frequent mountain streams and pools. The **Coleoptera** or Beetles are even less abundant than the **Hemiptera** or Bugs. There are only five species of water beetles, three of these belonging to the family **Dystiscidae,** and two species of **Hydrobius** of the family **Hydrophilidae.** Chief among the **Diptera** or Flies may be mentioned the **Culicidae** or Mosquitoes with three species; **Chirono-**

* In the classifications, into orders and families, used throughout this thesis, that of Comstock's "Manual for the Study of Insects" has been followed as far as possible. The family **Naeogeidae** is not mentioned in this manual, thus one more is added to the ten mentioned therein.

midae or Midges, and **Ephydridae,** each with four species recorded. There are, no doubt, a great many more species in the last two families.

AERIAL INSECTS.

The adult dragonfly has a much greater range of food among the insects of the air than the nymph among the aquatic forms of life, as representatives of every order containing winged forms, except the four mentioned under the aquatic group as being entirely absent from the islands, are found locally. Each of the principal orders forming possible food for the **Odonata** will be taken up separately and briefly summarized.

COLEOPTERA or Beetles.

This order is the largest in the number of species, 1288 having been recorded, and these are distributed among forty-seven families. The four largest families, **Carabidae** or Ground beetles, **Cermabycidae** or Long-horned beetles, **Nitidulidae,** and **Proterhinidae,** comprising nearly one-half of the number of species of beetles, are mostly native and are practically all found in the Forest Zone. Nearly all the species of the first and fourth families are flightless. Representatives of these four families once extending into the Lower Zone are now fast disappearing on account of the predaceous habits of the **Pheidole** Ant. The families still represented in the Lower Zone are mostly those of foreign introduction, such as **Bostrichidae, Bruchidae, Nitidulidae, Ptinidae, Scarabaeidae, Staphylinidae** and **Tenebrionidae,** each with a few species. The **Rhynchophora** or Snout-beetles are also represented by a few species.

LEPIDOPTERA or Moths and Butterflies.

This order comes next in number. Most of the species are found in the native forests and belong mostly to the **Microlepidoptera** or Small Moths. A few "Micros," however, are also found in the Lower Zone, such as the leaf miners. Among the **Macrolepidoptera** or large moths and butterflies of this zone may be included eight of the ten butterflies found here, three of them cosmopolitan species, **Pontia rapae** Linn., the Cabbage butterfly; **Anosia plexippus** Linn., the Milkweed butterfly, and **Vanessa cardui** Linn., the cosmopolite butterfly. Among the moths are the introduced species of grain moth, and those of the native and introduced army worms and cutworms.

DIPTERA or Flies.

This order no doubt comes third, though very little systematic work has been done in this group so far. In all, twenty-six families have been recognized, of which ten contain endemic species. The forests are very rich in **Diptera** of all kinds. The principal families found in these wooded areas are: **Anthomyiidae, Cecidomyiidae, Chironomidae, Drosophilidae, Pipunculidae** and **Tipulidae.** The fourth named is very striking in number and development, 250 closely related species having been enumerated, most of which are native. In the lowlands, cultivated ground, and around habitations, a number of the cosmopolitan forms of the families **Anthomyiidae, Dolichopodidae, Drosophilidae** or Pomace flies, **Muscidae** or House flies, and **Sarcophagidae** or Meat flies occur; along streams and muddy pools, **Chironomids** or Midges and **Ephydrids** abound.

The **Culicidae** or Mosquitoes are represented by but three species: **Stegomyia scutelaris** Walk., a day mosquito, found chiefly in the upland forests, though also in lowlands and around dwellings; **Aedes calopus** Meig., the yellow-fever mosquito, also a day mosquito, but

very scarce; and **Culex fatigans** Wied., a night mosquito, quite common during the rainy season and to be found anywhere from sea level to 4000 feet elevation.

HEMIPTERA or Bugs.

The **Hemiptera** have a fair representation in these islands, about 300 species. This number is divided nearly equally between the **Heteroptera** and **Homoptera.** As with most of the other orders the majority of species here are native, and therefore found mostly in the Forest Zone. The **Heteroptera** of the Lower Zone are represented chiefly by the **Capsidae, Lygaedae** and **Nabidae.** Although some winged forms of each of these families are found in the lowlands, the majority are wingless and are found in the forests. **Pentatomidae** or Stink-bugs, and **Reduviidae** also occur. Among the **Homoptera** may be mentioned **Aphidae** or Plant lice, **Coccidae** or Scale insects, **Fulgoridae,** and **Jassidae** or Leaf-hoppers. The last two families contain more than half of the **Homoptera.**

HYMENOPTERA or Bees, Wasps and Ants.

The **Hymenoptera** form quite an interesting part of the Hawaiian fauna, as perhaps the majority of the species in this order are introduced and may therefore be met with chiefly in the Lower Zone. The **Aculeata** or Stinging Hymenoptera contain about 200 species, unequally distributed among the digger wasps, bees and true wasps. Among the **Terebrantia** or Boring Hymenoptera are now found a fairly large number of species, mostly introduced. There are a few families, however, that are entirely absent. Among those that have representatives are the **Braconidae, Chalcidae, Evaniidae, Ichneumonidae,** and **Proctotrupidae,** all parasitic.

NEUROPTERA or Lace-wings.

As in the previous order, here also a few families are absent; but unlike the **Hymenoptera,** most of the species of the **Neuroptera** are native and found chiefly in the forests. The families quite rich in species are **Chrysopidae** or Lace-wings and **Hemerobiidae.** The latter family contains two flightless genera. The **Embiids** are represented by one species, specimens of which are frequently seen in dwellings. The **Myrmeleonidae** or Ant-lions are represented by two species, but are rarely found.

ODONATA.

For details of this order see p.

ORTHOPTERA.

So far eighty-three species have been recorded in this order. Of the six families belonging to this order only one, the **Phasmidae** or Walking sticks is not represented. The **Gryllidae** or Crickets take the lead in numbers, about forty species being known. Next come the **Blattidae** or Cockroaches and **Locustidae** or Long-horned grasshoppers. Among these three families are found a number of flightless forms. The **Mantidae** or Praying Mantis and **Acridiidae** or Short-horned grasshoppers are represented each by two species.

EUPLEXOPTERA or Ear-wigs.

This order is represented by about a dozen species.

ISOPTERA or White Ants, or Termites.

Only four species have been recorded, and specimens may be found in both zones.

CORRODENTIA or Book-lice.

Twenty-five species of **Psocids** have been recorded, of which twenty-four are described as new in the "Fauna Hawaiiensis." Specimens of this order may be found in both zones.

THYSANOPTERA or Thrips.

This order is represented by five species, all of which are in the Lower Zone.

The remaining three orders, **Thysanura** or Silver-fish, **Siphonaptera** or Fleas, and **Mallophaga** or Bird-lice, although each represented by a few species, need no further mention, as their members are neither aerial, possessing no functional wings, nor aquatic, and therefore do not contribute to the food supply of the **Odonata.**

Scope of the Work.

This paper will confine itself to the **Anisoptera** or Dragon-flies of the Lower Zone. Of the three found in this zone on the Island of Oahu only two, **Anax junius** Drury and **Pantala flavescens** Fabr., were taken, as these are the most abundant. The third, **Tramea lacerata** Hagen, is very scarce and difficult to capture.

The data on the food habits of the nymphs were obtained chiefly by examining the contents of the alimentary canal. This is also largely true with regard to the adults. Although a great deal could be learned by field observation as to what insects the dragonfly catches on the wing, greater stress is laid on what was found in the digestive tract, including the mouth parts; in fact, this latter method may be considered a check, and in many cases it was used as a means to verify observation, especially in the case with small insects. A few remarks on the digestive organs will therefore not be out of place.

In all insects the kind and accessibility of food and the manner in which it is obtained determine the form and structure, not only of the external organs, but of the internal ones as well. Especially is this true of the alimentary canal. The insect that feeds on liquid foods, animal or vegetable, imbibing them by means of tube-like sucking mouth-parts, possesses a very different digestive tract from one with biting mouth-parts, which lives chiefly on the solid parts of other insects. The digestive tract of the former is long, tortuous, more or less smooth, has no gizzard and only a small crop. That of the latter is usually comparatively short and straight, possesses a crop capable of great expansion and a well defined gizzard which is variously lined with citinized prominences. Plate I, Figs. 1 and 4 show two forms of the latter type of alimentary

canal. Fig. 1 is that of the adult, and Fig. 4 that of the nymph of **Pantala flavescens** Fabr.

The gizzard of the dragonfly is immediately behind the crop and extends into the chylific stomach, so that, in addition to its main function of further grinding the food, it serves as a valve to keep food from returning from the stomach into the crop, as shown in Plate I, Fig. 2. The lining of the gizzard of the adult has four long and narrow chitinous strips running parallel with the long axis of the digestive tract. Each of these strips at the caudal end is surrounded with an area, extending about one-third the length of the strip, composed of very minute spiles, as shown in Plate I, Fig. 3.

In the nymph the gizzard is even more developed. Here, instead of narrow strips, there are two crescent-like plates crested with strong chitinous teeth. On the opposite side and fitting into the concave part of these crescents are two sets of chitinous prominences, each set composed of two large curved teeth. In Plate I, Fig. 5, the gizzard is laid open to show the lining.

Methods Employed.

In order to obtain data on the food of the dragonfly, two methods were employed in both the nymphal and the adult stages. With the nymph feeding in confinement, the contents of the alimentary canal were examined. With the adult, field observations were made and the contents of the alimentary canal were examined.

As it is well nigh impossible to obtain data on the food habits of the nymphs by mere observation under their natural conditions, most ponds and streams being of a nature to preclude such a course, this method had to be abandoned. The second method, examining the contents of the alimentary canal, is after all the only reliable one, and the conclusions will be based on the results of this method. The feeding of the nymphs in confinement was carried on in two different ways; by studying the local aquatic fauna, and then feeding the nymphs only such forms of life as were found in the ponds and streams with them; and, by placing in the rearing tanks all kinds of terrestial and aerial forms of insects, as well as other small forms of animal life.

With the adults a certain amount of field observation is possible, especially in the cases where the insects devoured are comparatively large. It is impossible, however, to tell with

certainty whether or not tiny creatures are caught, as the movements of the dragonfly are so quick, and so many of the small insects can be seen on the wing, if at all, only at a certain angle with the sun. Even in such cases we may verify our supposition when we have the good fortune of capturing the dragonfly immediately after it has caught its tiny victim, and the latter is not too greatly mutilated as it is being ground between the chitinous jaws of its captor. Quite often the species of such victims have been recognized, or, if not the species, at least the family to which they belonged.

In regard to the examination of the contents of the alimentary canal, it may seem at first thought that, since the food is so finely chewed up by the dragonfly, or nymph, and these tiny bits subjected to the further grinding of the more or less spined and chitinized lining of the gizzard, especially in the case of the nymphs, and lastly acted upon by the juices of the chylific stomach, very little is left that is recognizable in the digestive tract. Such, however, is not always the case. Enough chitinous matter in the form of scales, setae, legs, antennae, wings and bits of the hard integument itself are found, so that it is often possible, with the higher powers of the binocular, to classify the remnants of the insects into orders and families. For instance, the jagged scales of the **Lepidoptera** or butterflies and moths may be recognized, Plate III, Fig. 7; the broad, microscopically serrated, or smoothly pointed scales of **Culicidae** or Mosquitoes, Plate II, Fig 12; the wings and setaceous bits of integument of **Diptera** or Flies, Plate II, Figs. 9, 10, and Plate III, Fig. 13; and the characteristic venation and antennae of **Chironomidae** or Midges, Plate III, Fig. 2, (a) and (b). Obvious, too, are the partially membranous wings of **Heteroptera** or Bugs, Plate IV, Fig. 1; the characteristically veined wings, Plate II, Figs. 6, 11, and 14, and peculiar structure of the legs, Plate III, Fig. 15, of the **Homoptera** in general; and the one-segmented tarsi and wing venation of **Aphidae** or Plant lice, Plate III, Fig. 5, (a) and (b). Unmistakable are the wings and antennae of **Hymenoptera** in general; and the peculiar legs and the branching hairs of the **Apidae** or Bees, Plate III, Fig. 11 (a), (b) and (c). The hard Elytra, Plate II, Fig. 2, and Plate IV, Fig. 8, the comparatively smooth and well clawed legs, and the characteristic antennae, suggests the **Coleoptera** or Beetles in general, while the short elytra and peculiarly clubbed antennae at once indicate the local **Staphylinidae,**

Plate II, Fig. 7a, just as the peculiar tibiae formed for digging characterize the **Scarabaeidae**, Plate III, Fig. 10b. And so on for the other orders and families.

So much for the general groups. It is often possible to recognize even specific characters. This may be done by observing what insects are present in the immediate locality at the time the dragonflies are caught, and capturing also a few specimens of as many species as possible, and then carefully comparing the parts found in the intestines with those of the insects caught at that time. In this way it was often an easy matter to recognize certain specific characteristic anatomical parts of a species, such as the size, shape, color and structure of, say, a tarsus, a tibia, or an antenna. Of smaller insects entire wings, or at least the greater portion thereof, are frequently met with, as shown in Plate III, Figs. 1, 4, 8, 9, 10, and Plate IV, Figs. 1, 7a, and 11.

Area Covered.

In the pursuit of this research the aim has been to cover as much territory around Honolulu as time and circumstances would permit, so as to include as many as possible of the varied conditions under which the dragonflies find their food in the Lower Zone.

For the nymphs, the following localities were visited: The taro patches, natural streams and irrigation ditches of the valleys of Kalihi, Nuuanu, Pauoa, Makiki, Moiliili to Waikiki; the vegetable gardens and rice fields of Keauhou district; the Moanalua gardens and rice fields; the large swampy district of Kahauiki, at present more or less abandoned; and the Waialae district.

The adult dragonflies, having practically no bounds to limit their field of action, may be seen everywhere hawking for their prey. They dart back and forth on the streets, swarming the cow-yards and around horses and cattle, flying in and around vegetable gardens, soaring over ponds and streams, and flashing among trees, especially when these are in bloom. Since these winged hunters are so active everywhere, specimens for dissection were caught, not only in the districts visited for nymphs, as listed above, but on the plains, valleys and foothills in and around Honolulu.

EXAMINATION OF THE CONTENTS OF THE ALIMENTARY CANAL OF NYMPHS.

In this connection three hundred and thirty-five nymphs, including forty-one **Anax** and two hundred and ninety-four **Pantala,** were dissected for the purpose of examining the alimentary canal. Out of the forty-one specimens of **Anax** six were found to have the digestive tract entirely empty; and of the two hundred and ninety-four **Pantala,** seventy-six had in their alimentary canal no traces of animal remains, being either entirely empty or containing some mud, gravel or algae. There were then left in all two hundred and fifty-three whose digestive tract contained some kind of animal remains.

In examining the contents of the alimentary canal of the nymphs, no such difficulty was found in identifying the fragments as with the adults. This is due mainly to two reasons; first, the range of prey of the nymphs is comparatively limited among the aquatic forms that possess a skeleton, external or internal, which is chitinous or bony enough to resist being completely dissolved or destroyed in its passage through the alimentary canal; second, the gizzard being well provided with a grinding apparatus—Plate I, Fig. 5—the food is therefore not so finely broken up by the mouth parts of the nymph as it is in the adult whose gizzard possesses a much less developed grinding structure, as is seen by comparing Plate I, Fig. 2, with Fig. 5. The mouth parts of the adult are more strongly built and better fitted for fine chewing than are those of the nymph. In the crop of the nymph, larvae of **Chironomus** or Midges and **Culex** or Mosquitoes were often found nearly intact. Although the gizzard of the nymph without doubt further breaks up the large soft pieces that enter it, it is problematic whether or not such hard pieces as bits of chitin are really much reduced in size.

In the list that follows will be given the different kinds of animal life preyed on by dragonfly nymphs, as represented in the contents of the digestive tract of the two hundred and fifty three **Anax** and **Pantala** nymphs dissected. The nymphs of these two species having shown no appreciable difference in their food habits, the results are therefore given under one table.

In order to have some basis upon which to construct a table showing in some way the relative amounts of the different

kinds of animals taken as food by the nymphs, the following scheme was adopted. The figures in the table represent units, or the number of times a certain species or group appeared in the series of dissections; that is, each distinctive species or group of animals, as classified in the table, whether found in large or small quantities in the contents of a single digestive tract, is given the value of one unit, or 1. For example, suppose there were found in one nymph 12 specimens of Cypris, 6 heads of Chironomid larvae, and 1 spiral shell, Mollusca, each of these three groups is represented as one unit, making three units for that particular nymph.

TABLE SHOWING THE FINDINGS IN THE CONTENTS OF THE ALIMENTARY CANAL OF 253 NYMPHS.

		Total
COLEOPTERA or Beetles.		
Dytiscidae, the smallest of the three species		16
DIPTERA or Flies.		
Chironomidae (Midges).		
Chironomus hawaiiensis, larvae	167	
Chironomus hawaiiensis, adults	4	
Chironomid larvae, undetermined	1	172
Culicidae (Mosquitoes).		
Mosquito larvae and pupae	12	
Mosquito adult	1	13
Dolichopodidae (Long-legged Flies)	1	
Adult fly, undetermined	1	2
HEMIPTERA or Bugs.		
Naeogeidae.		
Merragata hebroides	1	
Veliidae.		
Microvelia vagans	2	3
HYMENOPTERA (Bees, Ants, etc.).		
Myrmicidae.		
Pheidole megacephala	2	
Ants, undetermined	11	13
ODONATA.		
Libellulidae.		
Pantala flavescens, nymphs		6
CRUSTACEA.		
Cypris	108	
Shrimps	3	111
MOLLUSCA.		
Spiral shells		14
PROTOZOA or Single-celled animals.		
Euglena		30

ANNULATA or Segmented worms.	
Nereis	1
AMPHIBIANS.	
Tadpoles	8
FISH.	
Top Minnows (?)	1
Total	390

It will be seen from this table that by far the greatest part of food of the nymphs is furnished by the order **Diptera,** chiefly Chironomid larvae, mostly of the species **Chironomus hawaiiensis,** Grims. Next to the flies come the Crustaceans, with Cypris in the lead; and third comes the **Protozoa.** Least of all are the **Annulata** and fish, each represented by only one unit.

It may also be of interest to note that in this list the aerial insects have a small representation. Remains of ants, mostly, no doubt, **Pheidole megacephala,** Fabr., appeared in thirteen different nymphs; while the **Diptera** are represented by one mosquito, four Chironomids, one Dolichopodid and an undetermined species of fly, making in all twenty units. The species in both **Coleoptera** and **Hemiptera,** however, were those of aquatic forms.

There is no doubt but that the nymph is a great destroyer of mosquito larvae, although the table does not make a favorable showing in that respect. The reasons for this low percentage are obvious. Out of the many localities where nymphs were collected mosquito larvae were found in only two places. These were small depressions in an irrigating ditch still holding a small quantity of water while the other parts of the ditch had either run off or dried up. Fully half of the nymphs taken from one of these water pits contained remains of mosquito larvae in their digestive tracts, while all the nymphs from the other place showed on dissection that they had fed on larvae of the mosquito. One of the main reasons, perhaps, for mosquito larvae being so scarce in streams, ponds, rice fields and taro patches is the ubiquity of the little Top Minnow.

To present the relative quantities of these different kinds of food in a more concrete and simple form, the following graphic statement has been prepared:

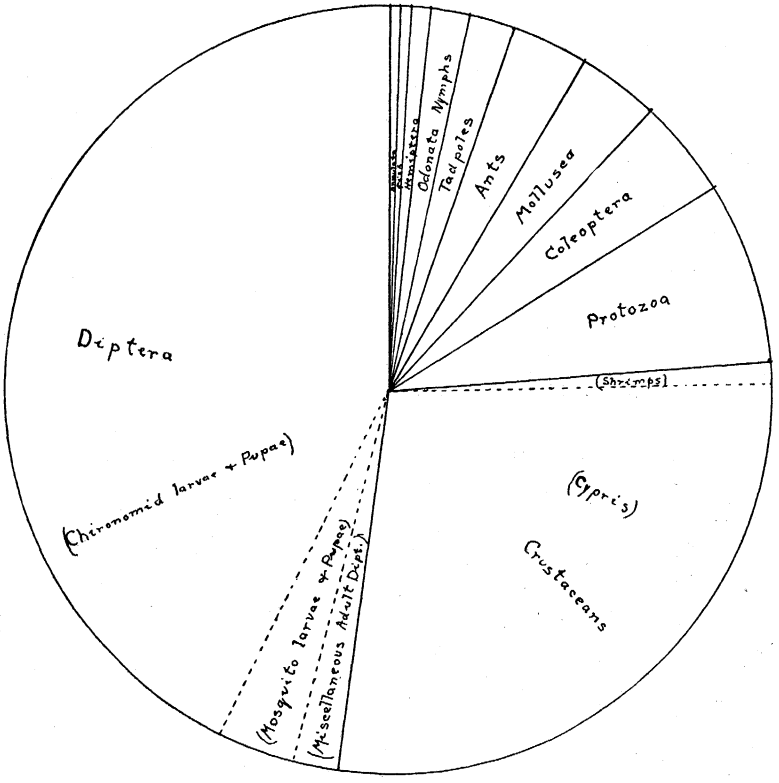

Fig. 1.—Chart showing graphically the proportion of the different kinds of food eaten by the 253 nymphs that were dissected.

Aquatic Animals as Food for Nymphs.

A second series of experiments was carried on in the laboratory with the view of finding out how far the food range of the nymphs extended among the aquatic forms of life. As in the former series of experiments, nymphs of both **Anax** and **Pantala** were employed. The food in this series was simply placed in the breeding jars or tanks where the nymphs were confined, and they were allowed to feed undisturbed at their leisure. All the different kinds of aquatic creatures placed in the vessels were eaten without exception. The following is a list of groups of water animals taken for the purpose:

CRUSTACEA.
- Fresh water shrimps.
- Cypris.
- Cyclops.

HEXAPODA or Insects.
- Coleoptera, Beetles.
  - Dytiscidae, 2 species.
- Diptera or Flies.
  - Chironomid larvae and pupae.
  - Ephydrid larvae
  - Hemiptera or Bugs.
  - Corisidae, Arctocorisa blackburni.
  - Naeogeidae, Merragata hebroides.
  - Notonnectidae, Buenoa pallipes.
  - Veliidae, Microvelia vagans.

FISH.
- Various kinds of fish.

ANNULATA, or Segmented worms.
- All kinds of segmented worms; among which were the following:
- Nereis or Earthworms, Leeches.
- Myriopoda or Thousand-legged worms.
  - Various kinds, such as were found in fresh water.
- Protozoa or Single-celled animals. Nematodes or Round worms, and Rotifera or Microscopic worms were eagerly eaten by the small nymphs.

Since so many of the aquatic forms, as listed above, were found in the contents of the alimentary canal of the nymphs caught in various places in the open, it is reasonable to suppose that practically all of these groups form the natural food of the dragonfly in its younger stages.

Among those forms that were found in countless numbers in many localities are the following, named in order of their abundance, beginning with the most numerous: **Chironomid** or Midge larvae, mostly those of **Chironomus hawaiiensis; Nereis** or Segmented worm; **Cypris** or Small crustacean.

The Chironomid larvae are ubiquitous, and in some places were found in such abundance that dozens could be caught by one swoop of the net. Judging from their great abundance and the number of specimens found in the stomach contents of many different individual nymphs, these larvae no doubt furnish a large share of their food of the young stages of the dragonfly, as will be shown in the dissection experiments. **Nereis** and **Cypris** are also very abundant in muddy streams and pools. The former in some places were so abundant that the mud in which they live appeared decidedly red. However, in spite of this fact, no trace of them could be found in the digestive tract of the nymphs, but this is undoubtedly due to the non-chitinous structure of their body. Although **Cypris** seem to be composed mostly of hard shell, they nevertheless figure considerably in the food supply of the nymph, as is shown in the table on page 25.

Land Insects as Food for Nymphs.

It has been suggested that, since the Hawaiian streams and other bodies of fresh water contain very few kinds of aquatic insects, and since the yellow and blue dragonflies are so numerous in many localities, the nymphs must obtain some part of their food from other sources than from the purely aquatic creatures. This outside food is thought to be derived from the occasional accidental dropping into the water of aerial insects; or, during freshets when extensive areas of vegetation are suddenly inundated, from the large numbers of insects that drown and are swept into the main water channels.

In order to find out if the nymphs really do feed on aerial forms, if given an opportunity, a series of experiments was carried on by feeding the nymphs, both **Anax** and **Pantala,** while in confinement. Only aerial insects were given them, and these in most cases were dropped into the feeding jars alive. Some of the nymphs were carried through in this way for one or two moults, or until they finally emerged. In some cases this feeding period was carried on for from two to five weeks. The many species of insects proffered were readily eaten, except most of the ants, especially those strong in formic acid, and the black orange aphis, **Myzus citricidus** Kirk. Although these were snatched at repeatedly, they were as often rejected.

In these feeding experiments insects representing the following families were used:

COLEOPTERA or Beetles.

Bostrichidae
Bruchidae
Carabidae
Cerambycidae
Cucujidae
Dermestidae
Elateridae
Hydrophilidae
Nitidulidae
Ptinidae
Scarabaeidae
Tenebrionidae

DIPTERA or Flies.

Anthomyiidae
Chironomidae
Culicidae
Dolichopodidae
Drosophilidae
Tryetidae
Ephydridae
Muscidae
Psychodidae
Stratiomyiidae
Syrphidae

EUPLEXOPTERA or Earwigs.

Forficulidae

HEMIPTERA or Bugs.

Capsidae
Cocidae or Mealybugs
Fulgoridae
Jassidae
Lygaeidae
Reduviidae

HYMENOPTERA or Bees, Ants, Etc.

Apidae or Honey Bee
Formicidae, Camponotus maculatus Hawaiiensis
Braconidae
Evaniidae
Eumenidae
Ichneumonidae
Myrmicidae, Pheidole megacephala

LEPIDOPTERA or Moths and Butterflies.

All kinds of Micrclepidopters that could be obtained for the purpose were fed, and also some species of Macrolepidoptera.

NEUROPTERA or Lace-wings, Etc.

Embiidae

ORTHOPTERA.

Acridiidae or Short-horned Grasshoppers
Blattidae or Cockroaches
Gryllidae or Crickets
Locustidae or Long-horned Grasshoppers.

THYSANURA.

Lepisma saccharina, Silver-fish.

MALLOPHAGA.

Chicken lice.

Miscellaneous.

Besides adult insects, caterpillars, maggots and grubs of various kinds, other small creatures, such as spiders, land crustaceans or shrimps and sowbugs, millipedes or thousand-legged worms, earthworms, and nematodes or round-worms, were fed to the nymphs. All these were eagerly snatched at and eaten. Often when no other food was available, small bits of fresh beef seemed to be relished.

These experiments would indicate then, that if there is no other food available and land insects come within reach, they are eaten by the nymphs, provided these land insects are still alive and struggling or at least are moved by a current of water or air. As far as the habits of the nymphs were observed in connection with these experiments, they grabbed only at moving objects, whether animate or inanimate, except in one case when forty-three dead mosquitoes* were placed in a glass with a nymph and all but three were eaten. But in this case it was observed that the rectal breathing of the nymph set up a current of water which set the mosquitoes dancing around, and each time one floated within reach of the nymph the latter immediately snatched it up.

Just what percentage of the food of the nymph land insects form, under natural conditions, is hard to say. Only the dissecting of a very large number of nymphs would throw more definite light on this subject. That in nature some land insects are eaten, however, was proved by finding remains in the digestive tracts of a few nymphs. Out of three hundred and thirty-five dissected, eighty-two of which were empty, twenty were found to contain aerial forms, thus representing 5.97 per cent of the entire number dissected; or 7.90 per cent, taking only those two hundred and fifty-three whose digestive tracts contained some remains of animal life.

Examination of the Contents of the Alimentary Canal of the Adults.

In this series of dissections, two hundred and eighteen **Pantala** and twenty-four **Anax**, excluding those whose alimentary canals were found empty, were taken. The reason that so few specimens of **Anax** were dissected is because of their difficulty of capture, as they are swift on the wing and rarely fly low enough to be caught with the net. Dissection of the adults

*Cf. p. 35.

showed that they differ from the nymphs in that only about ten specimens in the entire series possessed in their alimentary canal no trace of food whatever. These empty specimens were either freshly emerged, still clinging to blades of grass along the edge of a body of water, or were caught so early in the morning that they had had no chance of catching prey; but later in the day no specimens were found whose alimentary canal was empty. This gives another proof of the indefatigable activity and the insatiable appetite of the adult dragonfly.

During this research, quite a number of adult specimens when caught were found to have some insects or portions of insects still in their mouth parts. As the mouth parts are really part of the digestive tract, the insects found in this way will be included with those found in the alimentary canal proper. In order to have some comparison as to the number or quantity of the different kinds of insects caught, the same unit basis that was adopted in connection with the nymphs is also used in this case.

As far as the results of this research would indicate, there seems to be a slight difference in the food habits between **Pantala** and **Anax**; the findings of these two species will therefore be given in separate tables, as follows:

TABLE SHOWING THE FINDINGS IN THE CONTENTS OF THE ALIMENTARY CANAL AND MOUTH PARTS OF 24 ADULT ANAX.

COLEOPTERA or Beetles.		
Scarabaeidae.		
Psammodius sps.	6	
Undetermined sp.	1	
Undetermined beetle	1	8
DIPTERA or Flies.		
Culicidae or Mosquitoes	3	
Undetermined flies	4	7
HEMIPTERA or Bugs.		
Fulgoridae.		
Siphanta acuta		1
HYMENOPTERA or Bees, Ants, Etc.		
Apidae or Bees.		
Apis mellifica, Honey bee	11	
Formicina or Ants	5	16

LEPIDOPTERA or Moths and Butterflies.		
Caradirinidae.		
Cirphis unipuncta, Cutworm	1	
Pyraustidae.		
Hymenia fascialis, Beet web-worm	1	
Undetermined forms	9	11
ODONATA or Dragonflies.		
Agrionidae.		
Agrion sp.	1	
Libellulidae.		
Pantala flavescens	1	2
MISCELLANEOUS.		
Mite		1
Total		46

TABLE SHOWING THE FINDINGS IN THE CONTENTS OF THE ALIMENTARY CANAL AND MOUTH PARTS OF 218 ADULT PANTALA.

COLEOPTERA or Beetles.		
Bostrichidae.		
Rhizopertha pusila Fabr.	1	
Scarabaeidae.		
Psammodius ps.	22	
Undetermined sps.	2	
Staphylinidae	31	
Undetermined Beetles	28	84
DIPTERA or Flies.		
Chironomidae or Midges.		
Chironomomus hawaiiensis	1	
Culicidae or Mosquitoes.		
Culex fatigans, Night Mosquitoes	1	
Stegomyia scutellaris, Day Mosquitoes	1	
Not determinable	3	
Drosophilidae or Pomace flies	3	
Undetermined flies	140	154
HEMIPTERA or Bugs.		
Aphidae or Plant lice	24	
Corisidae.		
Corixa blackburni	4	
Fulgoridae or Leaf-hoppers.		
Perkinsiella saccharicida	4	
Undetermined sp.	1	
Jassidae or Leaf-hoppers.		
Draeculacephala mollipes	3	
Nesophrosyne perkinsi	3	
Lygaeidae	2	
Tingitidae.		
Teleonemia lantanae	4	45

HYMENOPTERA or Bees, Ants, etc.		
Apina, not Honey Bee	1	
Braconidae.		
Chelonus blackburni	1	
Formicina or Ants.		
Myrmicidae.		
Pheidole megacephala	6	
Undetermined Ants	11	
Mymaridae.		
Paranogrus optabilis (?)	1	
Other Hymenopterous Parasites	3	23
LEPIDOPTERA or Moths and Butterflies.		
Tineidae.		
Cremastobombycia lantanella (?)	5	
Undetermined forms	72	77
ODONATA.		
Agrionidae.		
Agrion sp.	1	
CORRODENTIA or Book Lice.		
Psocidae	8	
THYSANOPTERA or Thrips.		
Thripidae	9	
MISCELLANEOUS.		
Mite	1	
Spiders	2	21
Total		404

Comparing the foregoing tables the chief difference in the food of the two species is that the **Anax** goes after larger game than does the **Pantala.** Besides the beneficial work that the former species performs in feeding on such injurious insects as moths of army worms and beet web-worms, lantern bugs and mosquitoes, it also preys on beneficial ones, such as other species of dragonfly, and honey bees. Of the twenty-four specimens dissected, eleven contained remains of the honey bee. Just how destructive the large blue dragonfly is among domestic bees is hard to say, as no definite conclusion can be drawn from the present meager data. More information on this subject would be of great interest, particularly to the beekeeper.

The **Pantala** on the whole seem to feed chiefly on small insects, the majority of which are injurious, or of no practical economic importance. Among the injurious ones found may be mentioned leafhoppers, all kinds of small moths and flies, mosquitoes, plant lice, ants, and thrips. The list also includes beneficial insects, such as egg-parasites and internal parasites,

most of which are very small. However, the number of beneficial creatures caught by the dragonflies is no doubt very small, as none was found in connection with the **Anax** series, and among the two hundred and eighteen **Pantala** examined there were found altogether but five, viz.: one **Braconid,** one **Mymarid,** both parasitic, and three undetermined forms. The large number of injurious insects that are destroyed by the dragonflies well compensates for the few beneficial ones eaten by them.

As will be seen, two mites and two spiders are recorded in the tables. The former were no doubt parasitic on flies or beetles caught by the dragonfly and devoured with the host, as mites are not infrequently met with on members of **Diptera**

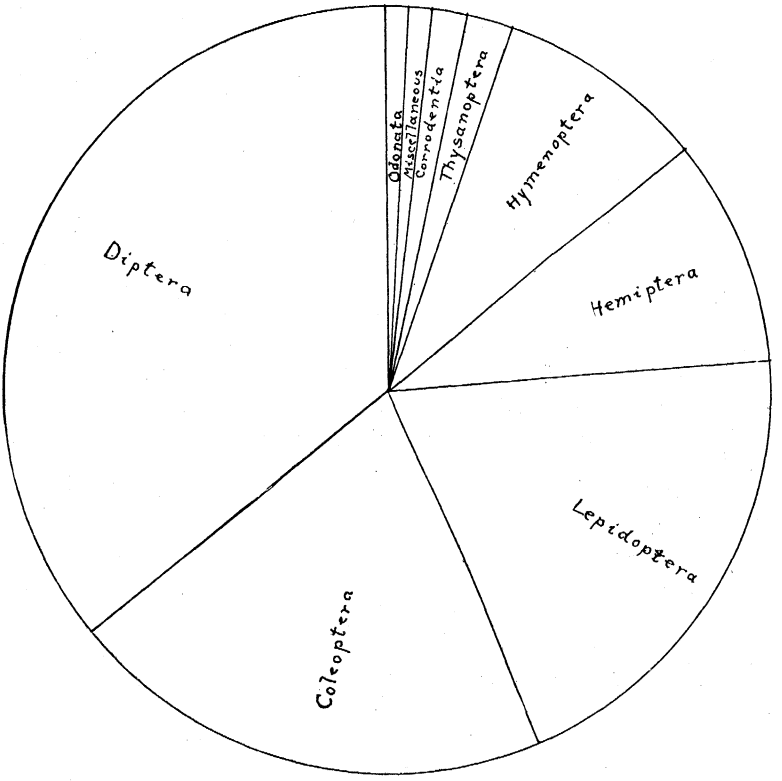

Fig. 2.—Graphic chart showing the proportion of different insects and small animals eaten by 218 full grown Pantala and 24 Anax.

and **Coleoptera.** The only explanation for the spiders included in the menu of the dragonfly is that they were caught while swinging in mid air, as they often do, suspended from a thread of silk of their own manufacture.

The following chart will give in graphic form, as in the case with the nymphs, the relative amounts of the different kinds of insects constituting the food of the adult dragonflies. This chart is based upon the two foregoing tables and therefore includes the findings of both species of dragonfly observed.

As will be noted, by far the greatest representation is made by the order **Diptera,** totaling 161 units. Next come the beetles with 92 units, and these are closely followed by the **Lepidoptera** with 88 units. The **Hemiptera** and **Hymenoptera** were less abundant, the former representing 26 units and the latter 39.

Eating Capacity of the Dragonfly.

There is no doubt that the dragonflies are a great factor in helping to keep in check insects of all kinds. This is clearly seen by observing the adults hunting their prey almost incessantly. Their appetite is so keen that it can be satisfied by no insignificant number of the smaller insects. Though the dragonflies may be seen on their hunt at any hour of the day, they seem to show the greatest activity in the morning soon after sunrise and again in the evening a little before and at sunset. After the dragonflies have gorged themselves with food they would seem to alight on grass or some shrub or tree, there quietly to digest it. In walking across a field during the day one frequently encounters dragonflies darting away from such places. The food doubtless passes through the alimentary canal in a very few hours at the most. At the end of this time, or perhaps long before, they are again ready to resume their chase.

It is impossible to form an accurate estimate, either by field observation or by examining the stomach contents, of how much the adult dragonfly is capable of devouring in a day, as more often than not only a small portion of the prey is eaten, except in soft bodied insects, such as flies and plant lice, the rest being either rejected or accidentally dropped. However, the number of insects that fall a prey to a dragonfly during the course of its life must be enormous. Some idea of the volume of the food consumed by one of these voracious hunters may be gained from the few following observations and experiments:

The large blue dragonfly, **Anax junius,** has been observed capturing and eating a specimen of the common yellow species, half as large as itself; after devouring practically all of its victim, except the wings and perhaps some of the legs, it was off chasing after other game. One day while watching a half dozen or more yellow dragonflies darting back and forth in a sunny corner of a rice field hedged in by high bushes where a swarm of minute **Chironomids** or Midges were basking in the sun, the writer could see that these flies were captured in great numbers. Four of these dragonflies were caught, and on dissection every one of the four was found full, from oesophagus to rectum, of the remains of these minute **Diptera.** A comparison of the bulk of the entire contents of the alimentary canal of one dragonfly with the bulk of one of these Chironomids would indicate that at a conservative estimate there must have been at least fifty of these flies.

The nymphs are perhaps even more voracious than the adults, judging from the amount of food they devour in captivity and also from what can be inferred by examining the stomach contents. For example, nine half-grown top-minnows were placed in a jar with four nymphs. In twenty-four hours all were eaten. In another case one nymph ate three half-grown top minnows in twelve hours.

To test a nymph's liking for aerial forms of insects, one evening forty-three mosquitoes, **Stegomyia scutellaris,** previously stunned by means of cyanide fumes, were placed in a glass with a **Pantala** nymph, the glass being less than half full of water. The next morning all the mosquitoes but three were eaten.

Their capacity for food as well as their cannibalistic character is well shown in the following experiment. Seventy (sixty-nine **Pantala** and one **Anax**) nymphs of various sizes were placed in a small tank and provided with no food except a small top minnow. In a week there were left seven **Pantala** and one **Anax,** and the little fish, so that sixty-two nymphs were eaten by their fellows.

One morning a **Pantala** nymph, in a glass half-full of water, was given seventy-five full-grown mosquito larvae. By noon fifteen were left and by seven o'clock in the evening all were eaten. This amount of food consumed during the day did not seem to satisfy the appetite of this nymph, as it eagerly devoured an additional lot of mosquito larvae that were placed in

the glass. When procurable, from forty to fifty full-grown mosquito larvae were fed each day for several days in succession to individual nymphs, and each time the amounts offered were eaten.

In dissecting the nymphs from a certain locality it was found that **Chironomus** larvae formed the main food; in several cases the number of larvae heads reached as high as twenty-five, fourteen to seventeen heads being quite commonly met with. In another district **Cypris** seemed to be the staple food, as these Crustaceans were found in great abundance in the digestive tract of both the **Pantala** and the **Anax** nymphs. As high as forty-eight whole specimens, together with a lot of crushed ones, were found in the stomach and crop of a single nymph.

Summary and Conclusion.

The data obtained on the food habits of the dragonfly during this research and recorded here, are by no means exhaustive or final, but they should be considered merely as a beginning of a study which has heretofore received little attention. Some idea of the food habits of this group of insects may be gained and something of their economic importance to the rest of the insect fauna under Hawaiian conditions realized.

The foregoing tables will show the many species and genera of insects that the writer was able to identify among the remains taken from the digestive system of the dragonflies. The great importance of these predators in the destruction of numerous noxious forms is evident. Their extreme usefulness as destroyers of mosquitoes, however, is not fairly shown, for the reason indicated in the text.

Summing up, it was found that the two species of dragonflies studied have a fairly wide food range among the insects of Hawaii. Only four of the twelve possible natural orders of insects are unrepresented in Hawaii. Of the orders present no representatives of the earwig, termites, lace-wing and grasshopper families were discovered in the food eaten by the dragonflies. This insect might, however, draw on any flying group of insects for its food supply, and there is no doubt that if these researches are continued insects of the excepted groups will be found to be occasionally included.

In addition to the insect diet, which is shown graphically in the charts, it will be seen that the nymphs feed rather extensively upon other aquatic animals—those identified being Protozoa, Annulata, Mollusca, Crustacea, tadpoles and fish.

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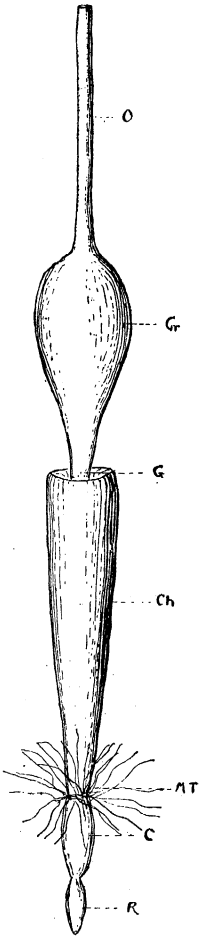

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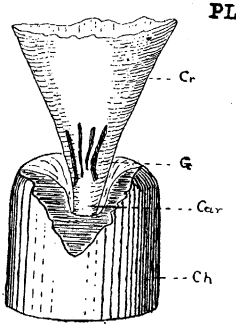

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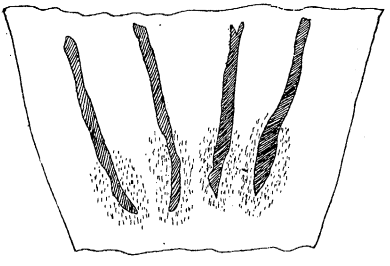

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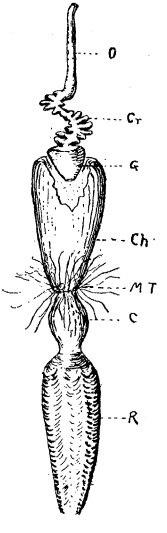

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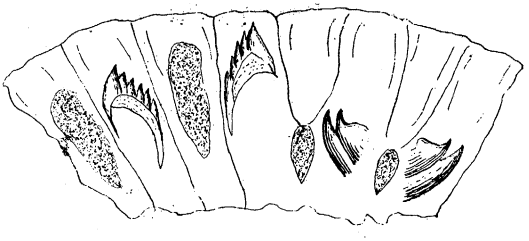

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A.Warren

EXPLANATION OF PLATES.

Plate I.

Fig. 1.—Alimentary canal of the adult dragonfly, **Pantala flavescens** Fabr. O, Oesophagus; Cr, Crop; G, Gizzard; Ch, Chilific stomach; MT, Malphigian tubules; C, Colon; R. Rectum.

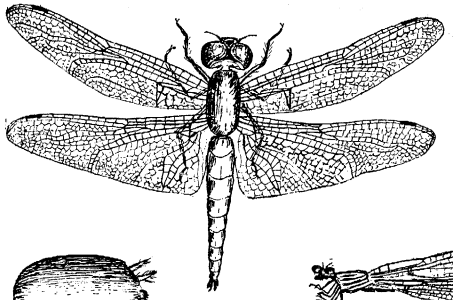
Fig. 2.—Part of alimentary canal showing cardiac valve. Cr, Crop; G, Gizzard; Car, Cardiac valve; Ch, Chilific stomach.

Fig. 3.—Gizzard laid open to show the four chitinous strips in the lining.

Fig. 4.—Alimentary canal of nymph, **Pantala flavescens** Fabr. Lettering the same as under Fig. 1.

Fig. 5.—Gizzard laid open to show the four sets of chitinous teeth.

PLATE II



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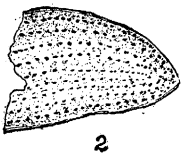

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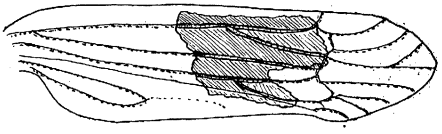

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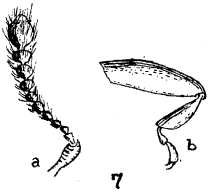

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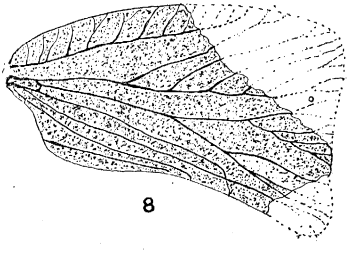

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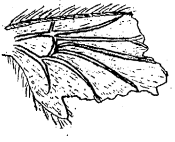

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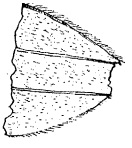

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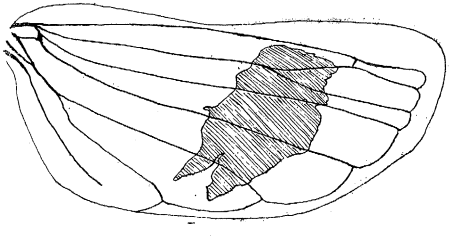

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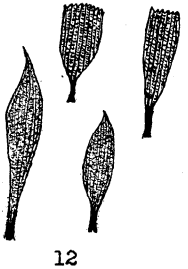

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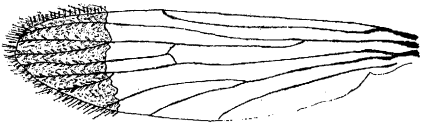

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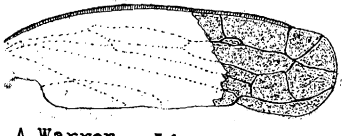


A.Warren 14

Plate II.*

Fig. 1.—**Pantala flavescens** Fabr., preyed upon by **Anax junius** Drury.

Fig. 2.—Part of an elytron of a beetle, species not determined.

Fig. 3.—A mite.

Fig. 4.—**Agrion** sp.; species of this genus are preyed upon by both **Anax** and **Pantala.**

Fig. 5.—Poison fang of spider.

Fig. 6.—Fore wing of leafhopper, **Perkinsiella saccharicida** Kirkaldy.

Fig. 7.—(a) Antenna of one of the smaller Staphylinids found locally. (b) Part of fore leg of same.

Fig. 8.—Fore wing of **Siphanta acuta** Walk. (**Fulgoridae**). The shaded portion is that part which was found in the mouth parts of an **Anax.**

Fig. 9.—Basal part of a Dipterous wing.

Fig. 10.—Distal part of a Dipterous wing.

Fig. 11.—Fore wing of **Draeculacephala mollipes** Say, (**Jassidae**).

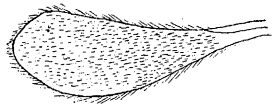
Fig. 12.—Scales of mosquito wing.

Fig. 13.—Wing of a mosquito.

Fig. 14.—Fore wing of **Nesophrosyne perkinsi** Kirk. (**Jassidae**).

* In Plates II, III, and IV parts of insects and other animals as pictured are, except when otherwise mentioned, of either nymph or adult dragonfly. In those cases where only parts of wings were found, the wing whenever possible was completed from that part as found; the portion supplied is unshaded, while the actual portion found is shaded.

PLATE III



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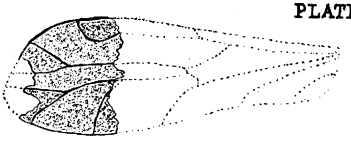

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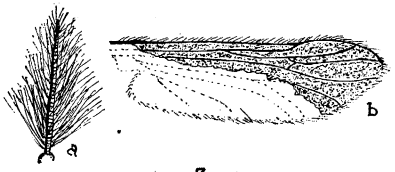

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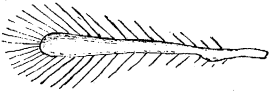

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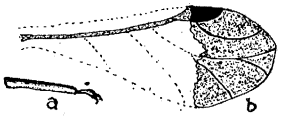

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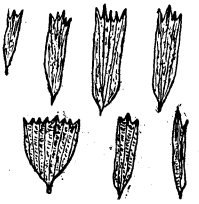

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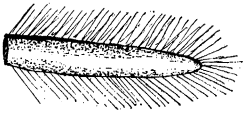

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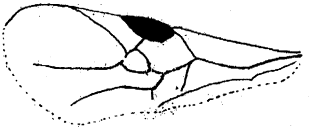

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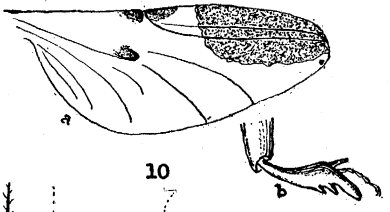

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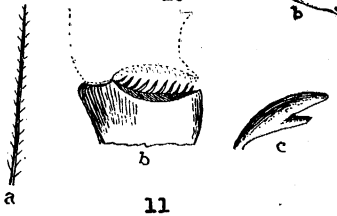

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Plate III.

Fig. 1.—Fore wing of a Hymenopterous parasite.

Fig. 2.—Fore wing of a Psocid.

Fig. 3.—(a) Antenna of male **Chironomus hawaiiensis** Grims. (b) Wing of same; the shaded portion is that part which was found in the mouth-parts of a **Pantala.**

Fig. 4.—Fore wing of a Mymarid, probably of **Paranagrus optabilis** Perk.

Fig. 5.—(a) Tarsus and part of tibia of an Aphid. (b) Fore wing of same.

Fig. 6.—Antenna of a Psychodid.

Fig. 7.—Lepidopterous scales.

Fig. 8.—Wing of a Thrip.

Fig. 9.—Fore wing of **Chelonus blackburni** Cam. (**Braconidae**). This wing, together with the anterior part of the abdomen of same, was found in the mouth-parts of a Pantala.

Fig. 10.—(a) Wing of **Psammodius** sp. (**Scarabaeidae**). (b) Part of fore leg of same.

Fig. 11.—(a) Hair of the honey bee, **Apis mellifica** Linn. (b) Pecten of hind leg of same. (c) Tarsal claw of same.

Fig. 12.—Arista of an antenna of a Dipteron.

Fig. 13.—Setaceous integument of a Dipteron.

Fig. 14.—Part of leg of a Dipteron.

Fig. 15.—Part of tibia of a Fulgorid (?)

PLATE IV

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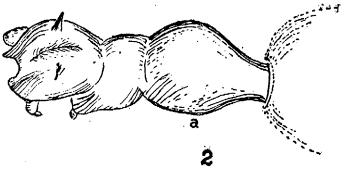

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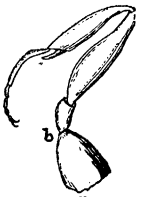

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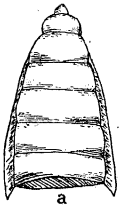

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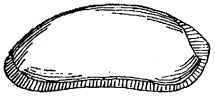

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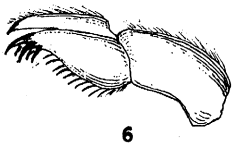

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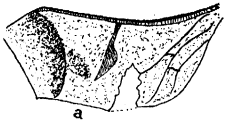

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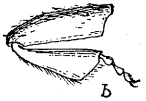

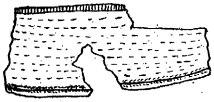

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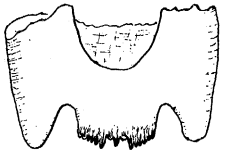

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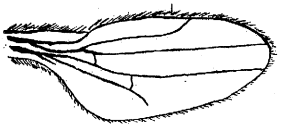

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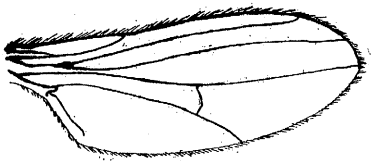

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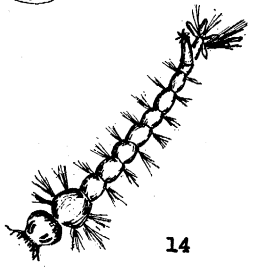


14

Warren

Plate IV.

Fig. 1.—Fore wing of **Merragata hebroides** White (**Naeogeidae**).

Fig. 2.—(a) Thorax of **Pheidole megacephala** Fabr. (b) Fore leg of same.

Fig. 3.—Spiral shell (**Mollusca**).

Fig. 4.—**Cypris (Crustacea).**

Fig. 5.—(a) Posterior part of abdomen of **Microvelia vagans** White **(Veliidae).** (b) Leg of same.

Fig. 6.—Mandible of nymph of **Pantala flavescens** Fabr.

Fig. 7.—(a) Wing of a Dytiscid, species not recorded in the "Fauna Hawaiiensis." (b) Fore leg of same.

Fig. 8.—Part of elytron of a beetle, not determined.

Fig. 9.—**Euglena (Protozoa).**

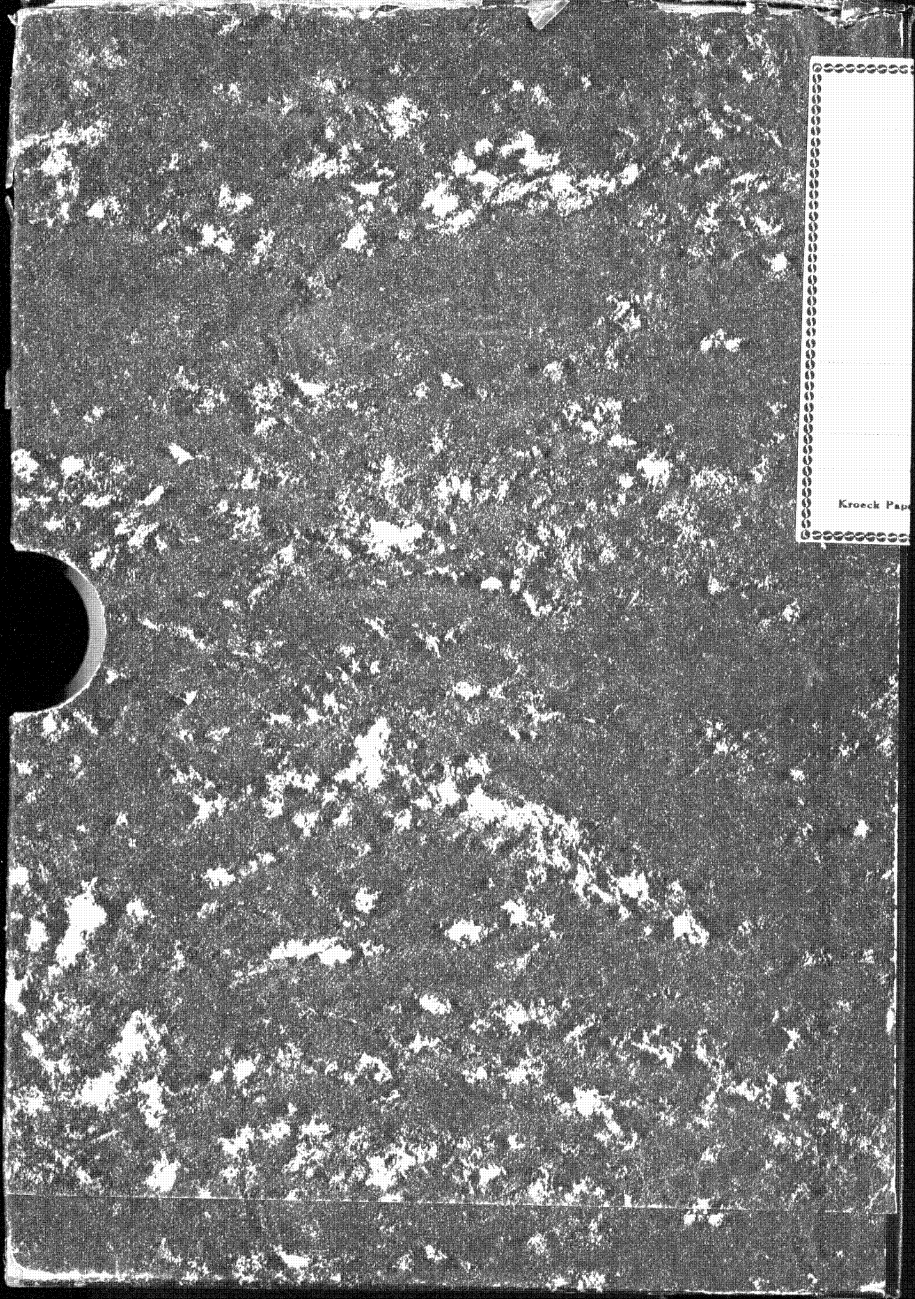
Fig. 10.—Ventral aspect of larval head of **Chironomus hawaiiensis** Grims., showing the labium.

Fig. 11.—Wing of minute fly, species not determined, probably of a species not yet recorded.

Fig. 12.—Scales of fish, probably of Top Minnow.

Fig. 13.—Wing of Dolochopodid, **Liancalus** sp.

Fig. 14.—Mosquito larva.


Kroeck Pape